



Application of twin screw extrusion technology for development of new generation snacks with antioxidant: An analysis

Mahuya Hom Choudhury, Runu Chakraborty, Utpal Raychaudhuri*

Department of Food Technology & Biochemical Engineering, Jadavpur University, Kolkata-700 032, India

***Correspondence to:** Department of Food Technology & Biochemical Engineering, Jadavpur University, Kolkata-700 032, India; E-mail: urcfoodtech@yahoo.co.in / mhc_123@rediffmail.com; Ph. No.+ 919830329408/+919007780898/913323211342; Fax: 913323211342

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ABSTRACT

The challenge in the field of extrusion technology is to produce unique, innovative products based on current market demands. Considering recent trends in producing ready to eat snack with herbal flavor, Rice, Chapra (*Fenneropeaneus indicus*) mixture powder were extruded with Aswagandha powder (*Withania somnifera*) for value addition by a co-rotating fully intermeshing twin-screw extruder. The extrudates were studied and characterized in respect of expansion ratio, shear stress, shear strength, acceptability, density, viscosity, micro-structural property as well as retention of antioxidant property. Acceptable product with high expansion ratio lower density and shear stress was obtained at 135° C and 15% process moisture condition. Viscosity of extrudate shows characteristic behavior. Micro-structural property analysis shows network like structure in scanning electron microscope. Stability of antioxidant property of Aswagandha after extrusion was also studied and retention of antioxidant property was observed.

Keywords: Extrusion, Chapra (*Fenneropeaneus indicus*), viscosity, Withania somnifera, chapra, Scanning Electron Microscopy, antioxidant

1. INTRODUCTION

Nutraceuticals is of today's interest in food science research. Most of the natural nutraceuticals in herbal forms are used in regular food habit in Indian dishes. However, herbs are mostly consumed in cooking condition and the essential extraction from herbs prepared by boiling destruct some properties due to long exposure to heating condition. Extrusion is widely used for continuous productions of expanded products like breakfast cereals and snack foods. Alavi et al. (1999), Moraru et al. (2003), Singh et al. (2007) investigated the importance of producing new generation snacks with improved nutritional characteristics. Chapra (*Fenneropeaneus indicus*) a local variety of shrimp has been used as food items in the coastal areas of West Bengal, India. USDA National Nutrient Database for Standard Reference, Release 15, (2002) and Dayal Syama et al Current Science. June 2013 analysed that the Chapra (shrimp) contains 20% protein, 1% fat, 76% moisture, 1.5 % ash and a good amount of minerals. A large amount of Chapra is wasted every year due to lack of proper preservation measures.

Mishra and Singh, 2000 investigated the plant *Withania somnifera* Dunn. (Aswagandha, WS), widely used in herbal formulations of Indian Ayurvedic medicine system to attenuate a cerebral function deficit in the geriatric population, and augment the faculty of learning and memory to provide a non-specific host defense. The plant aswagandha is widely available in different part of West Bengal, India and consumed through traditional extraction process. However, no work on herbal snack production using extrusion technology was found. In the present study, Aswagandha was used as raw material for value addition for rice, shrimp flour extrusion process. The objective of the study is to produce herbal snack using rice flour and Aswagandha through extrusion and to study the effect of extrusion variable on extrudate viscosity, microstructural property and antioxidant retention property. The study aims to characterize the extrusion process of rice and traditional medicinal herb to produce dried food. Attempt has been made to incorporate herbal medicinal antioxidant (Aswagandha) in the feed composition and also to analyze its retention property after extrusion cooking. Application of extrusion technology using herbal antioxidant produces new extrudate snack with herbal flavour.

2. MATERIALS AND METHODS

Materials

Rice (*Oryza sativa* L) and Chapra (*Fenneropeaneus indicus*) collected from coastal areas of West Bengal and salt (Tata) procured from local market was used for control formulation. Aswagandha (*Withania somnifera*) root and leaf collected from local market of Kolkata was used in the experiment.

Preparation of Feed for extrusion

Rice collected from local market was also washed and dried at the same condition. Chapra (*Fenneropeaneus indicus*) collected from coastal area was washed thoroughly in fresh water and the water was drained and then it was dried in an oven (800 W grill oven Sanyo, JP) at 60°C for 2 hours. After the water was completely removed, dried rice, Chapra were finely ground into powder form with a blender (Mixer Grinder, Bajaj, GM-550) separately. Rice, Chapra and Aswagandha powder (as extracted and prepared before extrusion) was mixed (5:1:1). The flour was sealed in polyethylene bags & stored at 4°C in refrigerator for 48 hours prior to extrusion.

Aswagandha powder preparation

Water soluble, high purity biologically active composition of Aswagandha root and leaf stock (1:1) was prepared following Ghosh Shibnath protocol, 2002.

Extruder & Extrusion cooking

A co rotating fully intermeshing twin screw Extruder (Model No. P1 Basic Technology Pvt. Ltd. Kolkata) was used (screw profile 12:1 barrel length 350 mm; barrel bore diameter 38 mm; screw diameter 37.8 mm; conveying angle 30°; intermeshing screws, 24 mm apart) for extrusion of the feed mixture of Rice flour and Aswagandha root and leaf extract in dried condition (1:1) using a 3 mm diameter die. The screw speed of the extruder was set at 475 rpm, while the feed rate was maintained constant at 28g/min. The extruder started functioning properly with said feed mixture at 110°C and at 11% feed moisture and stopped totally after 170°C and 19% feed moisture condition. Rice and Aswagandha flour mixture were extruded at four different process conditions. The temperature of the extruder barrel was thus maintained at 110°C, 130°C, 150°C & 170°C respectively and the moisture was adjusted to 11%, 13%, 15% and 17% adding the required amount of water to the flour mixture and conditioned at room temperature for half an hour.

Moisture Content

Moisture content of control and extruded products were measured using standard air oven (Model No-06104, SC Dutta & Co, Kolkata) according to AOAC (AOAC method of analysis, 15th edition) No. 14. 2002.

Expansion ratio

Expansion ratio was determined as the ratio of extruded product diameter to the diameter of the die. Values reported were averages of 30 measurements in each temperature and moisture combination as reported in optimization section.

Density

The density (ρ , $\text{mg}\cdot\text{mm}^{-3}$) was calculated as $\rho = 4M/\pi d^2 L$ where M = mass average of extrudate in mg (mean of 30 weighing in an analytical balance); D = diameter of the extrudate (mean of 30 measurements with vernier Caliper) in mm and L = Average length of extrudate in mm (mean of 30 measurements with a vernier caliper).

Shear strength

A universal Texture Analyzer (model-4301 Instron London, UK) was used in compression mode to record the required force to break extruded products. The extruded samples (5cm long) was placed on the platform transversally over a metal sheet support (1cm. thick) and operated in a compression mode with a sharp testing blade (3mm. Thick, 6.93 mm wide). The texturometer head moved the probe down at a rate of 15 mm/min until it broke the extrudates. Values reported were averages of 30 measurements in each temperature and moisture combination as reported in optimization section using load of 50N.

Texture Acceptability

Land and shepherd 1988 protocol was used to evaluate the sensory acceptance of the extruded product, a scale of 100 mm long was used). The texture acceptability score was defined as the distance from origin of the mark assigned on the scale by panelists relative to the central point on the scale which was assigned as the acceptability score of reference product (a commercial brand of unflavoured extruded corn). The panelist was instructed to consider only the texture and ignore the color and flavor. Every panelist assessed the texture with reference to relative texture acceptability of a standard sample coded with the letter p, and asked to indicate the score on the ballot.

Sample preparation for Viscosity studies

The extrudate and unextrudate material were grounded separately in a laboratory grinder to pass through 80 mesh BS sieve. 3 mg of the samples was mixed with 25 ml of distilled water in a petri dish and kept for one minute and then viscosity was measured using Rheometer (Model no. Physica MCR 51)

Table 1

Effect of Independent variables on response for rice, chapra (chapra), aswagandha extrusion

Assay	Independent Variable		Response Variable				
n ^a	Temperature °C X ₁	Moisture % X ₂	Expansion Ratio Y ₁ ^b	Shear Force (N) Y ₂ ^c	Shear Stress (N/m ²) Y ₃ ^d	Density ($\text{mg}\cdot\text{mm}^{-3}$) Y ₄ ^e	Acceptance of Texture (mm in a 100 mm scale) Y ₅ ^f
1	130	11	2.13±0.87	25.87± 0.17	4.35×10 ⁵ ±0.68×1 ⁵	0.62±0.01	49.86 ±2.54
2	150	13	2.45 ±0.7	21.33 ±0.14	3.89×10 ⁵ ±0.48×1 ⁵	0.45±0.01	62.11±8.67
3	110	11	2.22 ±1.31	23.33±0.44	3.45×10 ⁵ ±0.58×1 ⁵	0.63±0.01	53.11±3.02
4	150	11	2.22±0.21	24.11 ±0.42	3.77×10 ⁵ ±0.75×1 ⁵	0.62±0.01	48.96±3.54
5	110	13	2.42 ±.64	21.22±0.06	4.22×10 ⁵ ±0.35×1 ⁵	0.42±0.01	56.78±4.05
6	150	17	2.74 ±0.11	15.02 ±0.24	3.36×10 ⁵ ±0.27×1 ⁵	0.36±0.03	75.66±1.23
7	130	15	2.86 ±0.17	14.66 ±0.27	3.24×10 ⁵ ±0.35×1 ⁵	0.27±0.01	80.64±0.39
8	130	17	2.67 ±0.71	16.77 ±0.49	3.36×10 ⁵ ±0.37×1 ⁵	0.50±0.01	74.66±5.03
9	170	15	2.68 ±1.06	16.22±0.72	3.98×10 ⁵ ±0.57×1 ⁵	0.31±0.03	67.88±3.03
10	150	15	2.72 ±0.28	15.26±0.22	3.25×10 ⁵ ±0.42×1 ⁵	0.30±0.01	74.95±3.50

11	170	17	2.64 ±0.23	16.86 ±0.17	3.45×10 ⁵ ±0.46×1 ⁵	0.48±0.01	70.1±2.14
12	130	13	2.20 ±0.35	25.02±0.44	3.88×10 ⁵ ±0.32×1 ⁵	0.59±0.02	53.46±7.77
13	110	15	2.39 ±0.45	21.23±0.06	3.67×10 ⁵ ±0.28×1 ⁵	0.48 ± 0.03	62.33±7.00
14	170	11	2.75 ±0.57	18.87±0.12	3.92×10 ⁵ ±0.30×1 ⁵	0.31± 0.04	71.25±1.18
15	110	17	2.79 ±0.45	15.4±0.12	3.58×10 ⁵ ±0.30×1 ⁵	0.33± 0.05	75.35±1.10
16	170	13	2.40 ±0.49	21.2±0.07	3.32×10 ⁵ ±0.30×1 ⁵	0.63± 0.002	61.22±1.12

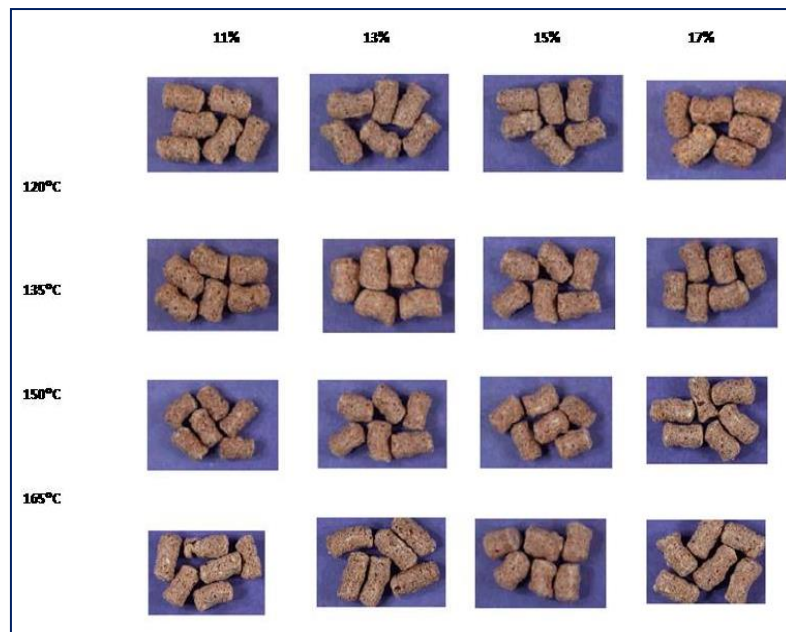


Figure 1

Extrudate produced by extrusion of rice shrimp and Aswagandha at different extrusion condition

a tray drier for one hour at 60°C and then the sample were freeze dried at the same temperature for one hour and dried powder was prepared using the blender (Mixer Grinder, Bajaj,GM-550) . 0.5g of extrudate processed at four different temperature range as mentioned in the extrusion cooking in powder form and normal dried powder was mixed separately with 2ml Methanol solution. To a known aliquot (0.1 ml) of the sample thus prepared was taken and mixed with 3.9 ml of DPPH (1,1-diphenyl 2-picrylhydrazyl) solution (100 ml in ethanol) was added, followed by incubation in dark for 45 min at room temperature. The decrease in the absorbance (due to the proton donating activity) was measured at 515 nm using a spectrophotometer (Shimadzu UV-160A, Kyoto, Japan). The DPPH radical scavenging activity was calculated as DPPH radical scavenging activity was calculated using the following equation.

$$\text{DPPH scavenging effect (\%)} = (A_b - A_s) / A_b \times 100$$

Table 2

Scavenging activity of rice chapra mixture

Sl. No.	Total antioxidant capacity test for rice shrimp feed mixture before extrusion	Result (O.D-Optical Density)
1.	Control	0.14
2.	Sample marked I (Rice, shrimp feed mixture)	-0.018*
3.	Sample marked II (Rice shrimp	-0.025*

Antioxidant property study

The Total Antioxidant Capacity (TAC) values of extrudate and unextrudate was tested by Randox (TAS) CAT. No. NX 2332 (Asadul Haque, et al 2006).

Microstructure Analysis:

Scanning Electron Microscope (SEM)

Scanning electron microscope (Jeol, JSM 5200, Tokyo, Japan) was used at an accelerating voltage of 20 kV to view extrudate in three dimension and to determine the shape and surface feature of extrudate. Extrudates from all the treatments and the control sample were mounted stubs with adhesive tape and sputters coated gold approx 190 Å thick for 2.5 min at 10 mA before observation with SEM. One micrograph was taken for each extrudate sample at 50X magnification and at 1000 X magnification for unextrudate sample. All the images for each sample showed representative result.

DPPH Assay

The DPPH radical scavenging activity of the samples were measured based on the method described by Shahriar et al. (2012). 100 µl concentration of DPPH solution is prepared rice:shrimp:aswagandha (5:1:1) were extruded at the condition mentioned and dried in

The free radical scavenging activity of different extracts of *Withania somnifera* root was studied by its ability to reduce the DPPH, a stable free radical and any molecule that can donate an electron or hydrogen to DPPH, can react with it and thereby bleach the DPPH absorption. DPPH is a purple colour dye having absorption maxima of 517 nm and upon reaction with a hydrogen donor the purple colour fades or disappears due to conversion of it to 2,2-diphenyl-1-picryl hydrazine resulting in decrease in absorbance.

Table 3

Scavenging activity of Rice chapra and aswagandha extrudate using DPPH method

Sample	Process Temperature (°C)	Extracts / standard	IC ₅₀ µg/ml before extrusion	IC ₅₀ µg/ml after extrusion
1.	Extruded sample at 120	Methanol	267.818	245.52
2.	Extruded sample at 135			266.34
3.	Extruded sample at 150			245.61
4.	Extruded sample at 165			240.12
5.	Traditional dried rice:shrimp: Aswagandha powder prepared at 60°C and 1 hr 15 minute heating exposure			235.78

Table 4

Scavenging activity of Rice chapra and aswagandha extrudate using RANDOX Kit

Sample	Process Temperature (°C)	TACmM/l of Trolox before the extrusion	TAC mmol/Trolox /Kg of Dm before extrusion	TACmM/l of Trolox After the extrusion	TAC mmol/Trolox /Kg of Dm
1.	Extruded sample at 120	1.6	16.58	1.51	15.65
2.	Extruded sample at 135			1.59	16.48
3.	Extruded sample at 150			1.56	16.17
4.	Extruded sample at 165			1.49	15.44
5.	Traditional dried rice:shrimp:Aswagandha powder at 60°C and 1 hr 15 minutes			1.1	11.40

3. RESULTS AND DISCUSSION

The physical properties of the extrudate obtained from the average of 30 measurements at 16 different extrusion conditions are presented in Table 1 for rice, shrimp (Chapra) and Aswagandha extrudates and the extrudates obtained at different extrusion condition are represented in Figure 1. The product with the most expansion ratio had the most appropriate texture for consumption for both the process and was obtained at 135°C and 15 % moisture. Also the greater the expansion, the lower the shearing force, the less the shear stress and the greater the textural sensory acceptability.

Marcotte et al., (2001) investigated the rheological property is an another important phenomena to study the flow conditions in food processing. Not only that, rheology is important for food texture and sensory data evaluation, understanding functionality in product

development and shelf life testing. Since rheology is the study of the deformation of matter, it is essential to have good understanding of stress and strain. The viscosities were studied to evaluate the effect of cooking temperature and moisture on the extrusion process of the Aswagandha and rice mixture. Patton and sprat (1981) suggested that viscosity profiles of cooked cereal products could be used to indicate their "degree of cooking" i.e, Viscosity is a sensitive indicator to evaluate the product characteristics. The viscosity of the extrudate shows negligible effect with change of moisture percentage and thus in the present study variation of viscosity of the extrudate with change of process temperature was noted.

In rheology, shearing of a substance is the key knowledge of flow behaviour and structure. Shear stress vs. shear rate values of rice and Aswagandha extrudate at four different experimental conditions is represented in Figure 2. Liang (2004) studied that Shear Stress vs. shear rate curve of extrudate at different process temperature fits Herschely Bulkley model. Initial shear stress increases with increase of extrusion temperature whereas after a certain shear rate value shear stress curve shows decrease with increase of process temperature. Thus shear stress increases with increase of extrusion process temperature from 110°C-130°C and sudden decrease observed between 150°C-170°C. Nature of curve shows non-Newtonian shear thinning behaviour.

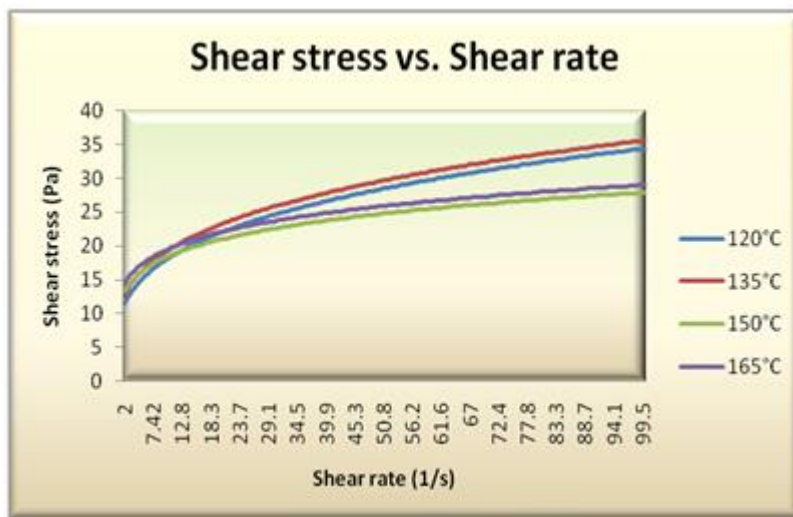


Figure 2

Shear stress vs shear rate value of extrudate at four different experimental condition i.e at 120°C, 135°C, 150°C and 165°C Barrel temp

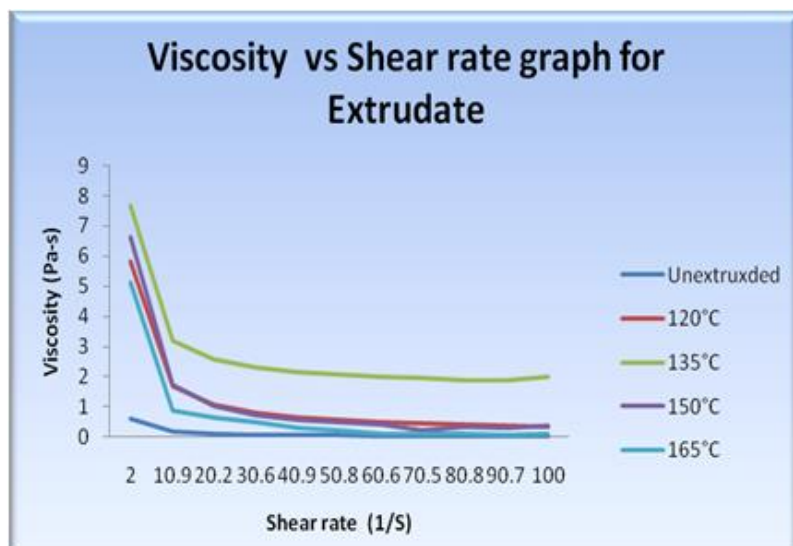


Figure 3

Viscosity vs shear rate of raw extrudate and extrudate at four different temperatures of rice, shrimp and Aswagandha

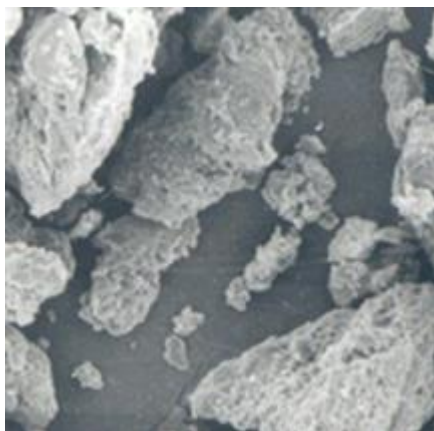


Figure 4

SEM picture of rice, shrimp and aswagandha unextruded flour

Viscosities vs shear rate values of raw extrudate and extrudate produced at four different temperatures represented in Fig. 3. Thus, Fig 3 shows viscosity at 110°C is 10 times higher value than that of raw extrudate mixture. The reason behind this behaviour indicates the faster hydration property of the gelatinized extrudate compare to raw sample. Viscosity value at 130°C process temperature also shows an increasing trend. Viscosity of extrudate decreases upon further increase of extrusion temperature. This initial increase in viscosity value indicated that fully gelatinized extrudate was obtained at 130°C and heating the slurries of completely gelatinized materials causes the decrease in the viscosity value at 150°C leading to the thinning of the slurry. The observations were validated with the observation of Schweizer et al., (1986). Application of thermal and mechanical Energy could result structural breakdown of starch granules as investigated by Gomez & Aguilera (1983), Holm et al. (1988 a, b), Cai et al. (1993). Pregelatinised degraded extrudate granules therefore lose their ability to swell upon heating in water, resulting in low viscosity. Not only that, presence of protein molecule also helps in structural network formation. As protein part of the feed material participated in the network formation, the final structure becomes rigid and result follows decreasing trend after a certain increase in initial viscosity from 110°C-130°C. Initial increase in shear stress (110°C-130°C) value is easily justified with the change of viscosity at the same process condition as change of shear stress of extrudate solution depend on flow behaviour of the extrudate. Fig. 3 also represents a decrease of viscosity value in the same temperature range with the increase of shear rate.

This change is indicative of non-Newtonian shear thinning behavior. Liang et al., (2004) investigated similar behavior of viscosity and shear rate.

Microstructure analysis performed by SEM revealed a expanded matrix with voids at 11%, 13%, 15% 17% moisture level and four different temperature process temperature at 120°C-165°C (Figure 4- Figure 8). Figure 3 distinctly shows three different size granules showing protein and carbohydrate present in the granules. In the optimal process, the maximum expansion ratio was seen at 135°C and 15% moisture (Figure 3). SEM picture at 135°C and 15% moisture level also shows large air cells and thinner wall in better symmetrical fashion. Thus SEM result also validated the result of most expanded product obtained at optimal process. SEM picture of the Extrudate at 17% moisture shows maximum shear in the granules i.e damage and breaking in continuous symmetrical structure and cell wall observed. Absence of starch granule in all figures indicated starch has been completely gelatinized.

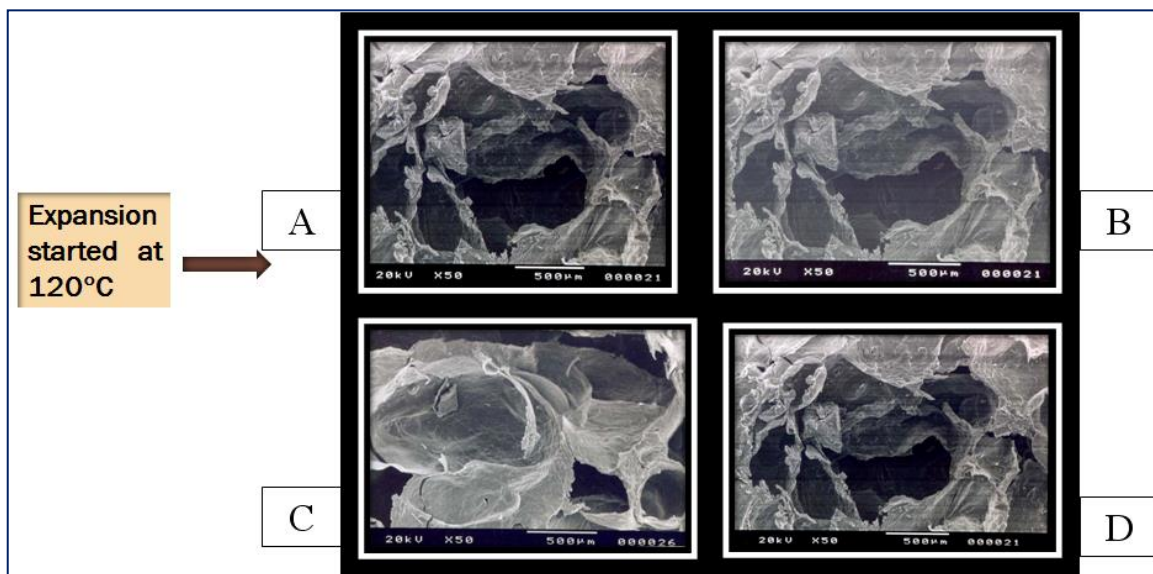


Figure 5

SEM picture of extruded product of rice, shrimp and Aswagandha extrudate for 120°C A) 11% B)13%C)15% D)17%

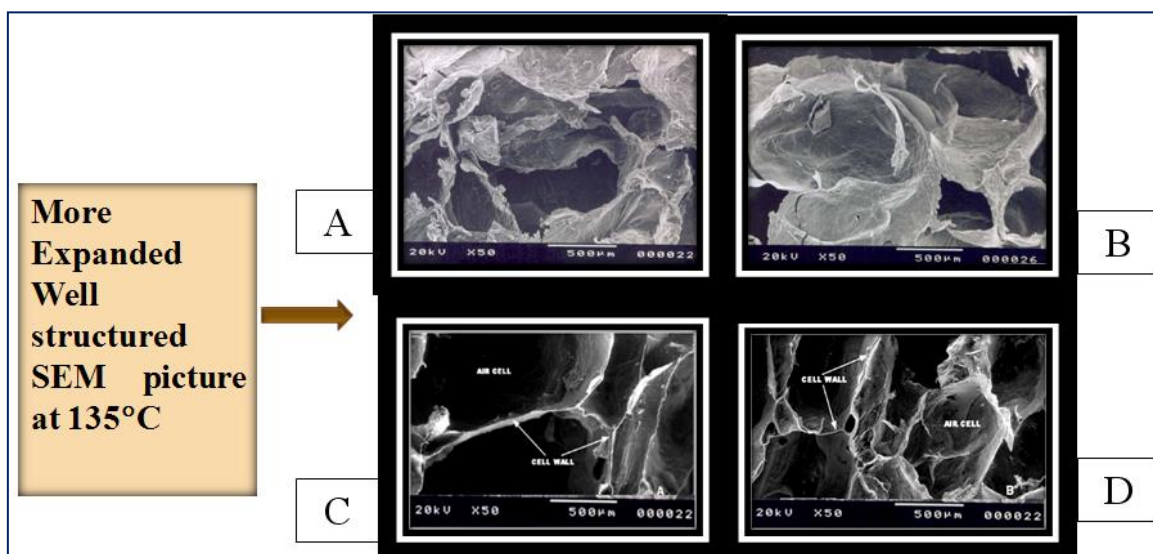


Figure 6

SEM picture of extruded product of rice, shrimp and Aswagandha extrudate for 135°C A) 11% B)13%C)15% D)17%

3.1. Microstructure analysis

3.2. Antioxidant Property of extrudate

IC₅₀ Indicate the potency of scavenging activity. Methanol extract of rice and shrimp feed sample indicated negative value (Table 2). Extruded sample of rice and shrimp feed mixture shows no antioxidant activity at all. Whereas methanol extract of extrudate (rice, shrimp and aswagandha) indicated 266.67 µg/ml before extrusion. The value of scavenging activity after extrusion was also noted and indicated in Table 3. Result shows highest retention at optimum process condition. (266.34). The Total Antioxidant Capacity (TAC) values of extrudate was also tested and validated by Randox (TAS) CAT. No. NX 2332 kit and the results are shown in Table 4. Study of aswagandha extrudate using the kit shows 1.6% (i.e. 16.58 mmol /Kg dry matter) of active Withaferin A (the active component responsible for antioxidant activity). Ghosal (2002) investigated the same. The matter clearly indicated that after cooking, the antioxidant property of Withaferin A present in Aswagandha (3.5%moisture) remains in the range of 1.1-1.59 mM/l of Trolox, which is equivalent to 11.40-16.48 mmol/Trolox/Kg dry matters. Thus the data revealed retention of antioxidant property after extrusion cooking at different extrusion condition. The data is supported with the observations Gujral Hardeep Singh (2012). However, with the increase of extrusion temperature amount of antioxidant present in the extrudate decreases and the lowest value

obtained at highest extrusion temperature at 165°C. The extent of retention is highest at optimum process condition (16.48). DPPH assay also indicated highest IC₅₀ at optimum condition. Result indicated 99% retention of antioxidant effect. Retention of antioxidant property of aswagandha was also supported by the negative result obtained in the feed mixture of shrimp and rice powder. Thus the antioxidant property of the extrudate indicated value addition using aswagandha. Change of antioxidant property with the change of moisture percentage was insignificant and not discussed. Extrudates obtained at optimum process temperature was considered. Traditional dried rice, shrimp, aswagandha powder obtained at 60°C shows lowest value whereas extrudate obtained at high temperature short time extrusion process shows higher retention even at 120°C. Thus long exposure at normal cooking temperature shows loss on total antioxidant capacity.

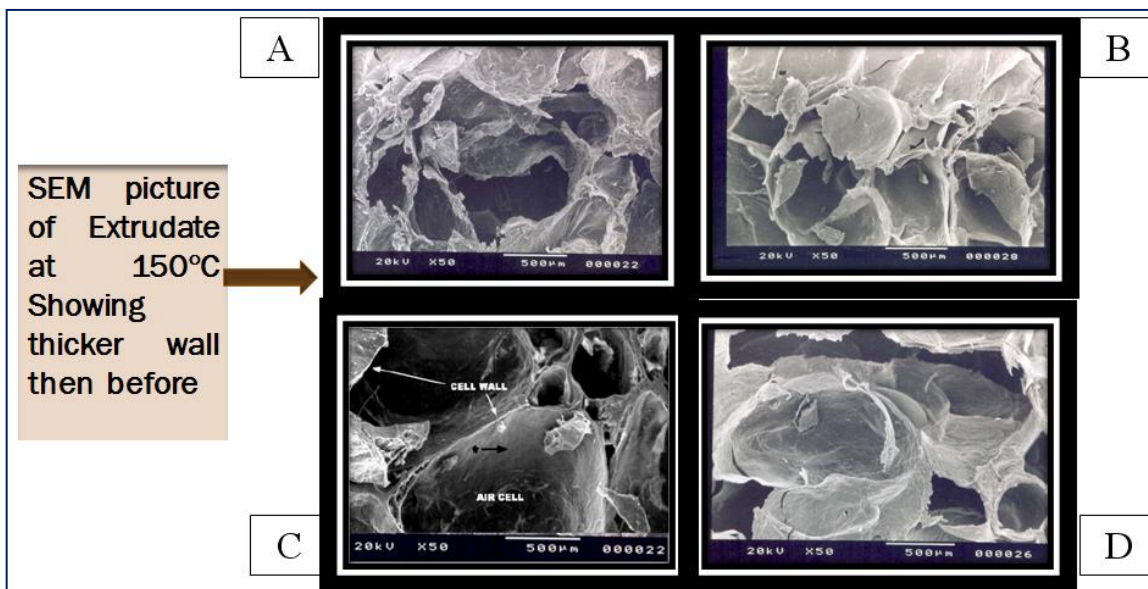


Figure 7

SEM picture of extruded product of rice, shrimp and aswagandha extrudate for 150°C A) 11% B)13%C)15% D)17%

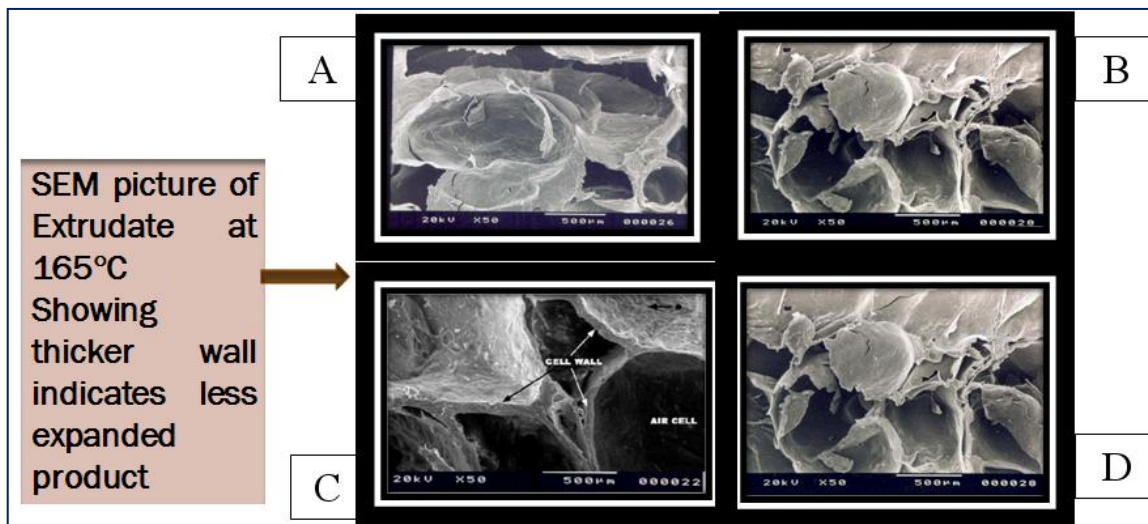


Figure 8

SEM picture of extruded product of rice, shrimp and Aswagandha extrudate for 165°C A) 11% B)13%C)15% D)17%

4. CONCLUSION AND RECOMMENDATIONS

The process parameters markedly affect the viscosity of rice and Aswagandha extrudate snack in respect of viscosity, microstructural property analysis. Initial viscosity of the extrudate suspension was about 10 times higher than that of raw material. Snack produced by extrusion cooking with low viscosity profile could be useful in the development of product in which higher solid content per unit

volume is required, such as specialty diet foods for children. The maximum expansion ratio obtained at 15% moisture and 135°C process temperature coincided with the minimum shearing force of the product, and maximum sensory texture acceptance of the product indicating a correlation between extrusion response variables. The study indicated the desired texture and sensory property could be obtained by controlling cooking temperature and moisture condition. Microstructural analysis performed by Scanning Electron microscopy revealed typical network structure of rice shrimp and herbal extrudate. Furthermore, investigation revealed nutritious snacks fortified with Aswagandha can be processed with retention of antioxidant property. Herbal snacks prepared through extrusion cooking shows more retention of antioxidant property rather than herbal extract prepared through traditional cooking process. The process of value addition using herbal antioxidant also need further study to improve its product quality and judge its nutritional quality as well as to improve market acceptability.

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REFERENCE

- Alavi SH, Gogoi BK, Khan M, Bowman BJ, Rizvi SSH. Structural Properties of protein-stabilized starch-based supercritical fluid extrudates. *Food Research International* 1999, 32, 107-118
- AOAC Methods of Analysis, 15th edn, (AOAC, Washington DC) 2002
- Cai W, Diosady LL, Rubin JJ. Degradation of Wheat starch in a twin screw extruder. *Journal of Food Engineering*, 1995, 26, 289-300
- Dayal Syama J, Ponniah A.G, Khan Imran H., Babu Madhu E.P., K Ambasankar, Vasgam Kumarguru K.P. Shrimps-a nutritional perspective. *Current Science*. 2013, 104, 10, 11
- Ghosal, Shibnath (Calcutta, IN, US) Withania Somnifera composition, method for obtaining same and pharmaceutical, nutritional and personal care formulations thereof United States Patent 6713092 dated 12/03/2002
- Gomez MH, Aguilera JM. Changes in the starch fraction during extrusion cooking of corn. *Journal of Food Science*, 1983, 48, 378-381
- Gujral Hardeep Singh, Paras Sharmaa, Arvind Kumara and Baljeet Singh. Total Phenolic Content and Antioxidant Activity of Extruded Brown Rice. *Int'l J of Food Properties*. 2012, 15(2)
- Holm J, Bjorck I, Eliasson AC. Effects of thermal processing of wheat and starch : II physicochemical and functional properties. *Journal of Cereal Science*, 1988b, 8, 145-152
- Holm, J, Bjorck, I & Eliasson. A.C. Effects of thermal processing of wheat and starch : I physicochemical and functional properties. *Journal of Cereal Science*, 1988 a ,7 249-260
- Land DG, Shepherd R, Scaling and ranking methods. Ch.6. In. Sensory analysis of foods, Piggott JR, editor, New Work. Elsevier Science Publishing Co. 1988, pp-155-167
- Liang Siqi, Sopade Peter A. thesis submitted in partial fulfillment of the requirements Bachelor of Engineering degree program in the Division of Chemical Engineering, The University of Queensland 2004
- Marcotte M, Hoshahili ART, Ramaswamy HS. Rheological properties of selected hydrocolloids as a function of concentration and temperature. *Food Research International*, 2001, 34, 695-703
- Mishra Lakshmi Chandra, Singh Betsy B. Scientific basis for the Therapeutic use of Withania somnifera (Aswagandha) A review. *Alternative Medicine Review*, 2000, 5(4), 334-345
- Moraru CI, Kokini JL. Nucleation and Expansion During Extrusion and Microwave Heating of Cereal Foods. *Comprehensive Reviews In Food Science And Food Safety*, 2003, 2, 120-138
- Patton, Sprat WA. Simulated Approach to the estimation of degree of cooking of an extruded cereal product cereal chemistry, 1981, 58, 216
- Schweizer II, Reimann S Solms. Influence of drum drying and twin screw extrusion cooking on wheat carbohydrate. II. Effects of lipid on physical properties degradation and complex formation of starch in wheat flour, *Journal of Cereal Science*. 1986, 4, 249-260
- Singh S, Gamlath S, Wakeling L. Nutritional aspects of food extrusion : a review. *International Journal of Food Science & Technology*, 2007, 42(8), 916-929
- USDA National Nutrient Database for Standard Reference, Release 15 (August 2002)